Chapter 12

Upper Mississippi River Case Study

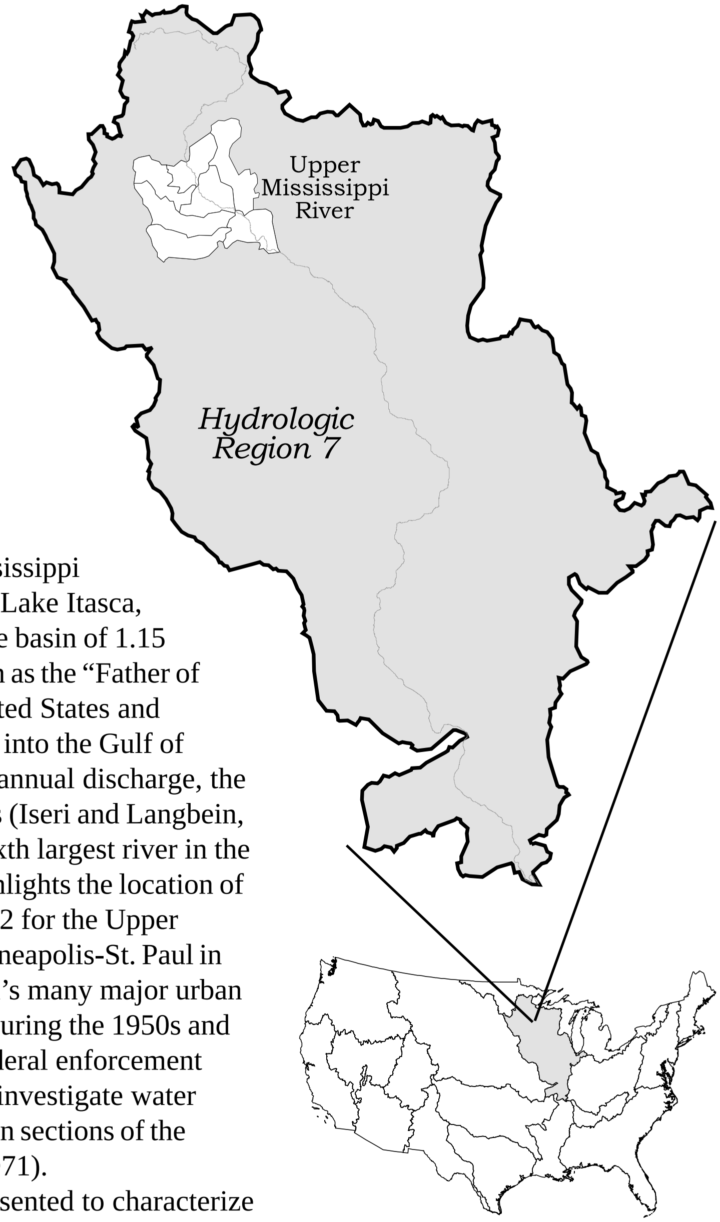


Figure 12-1
Hydrologic Region 7 and the Upper Mississippi River basin near Minneapolis-St. Paul, Minnesota.

The upper and lower watersheds of the Mississippi River extend 2,340 miles from the headwaters in Lake Itasca, Minnesota, to the Gulf of Mexico. With a drainage basin of 1.15 million square miles, the Mississippi River, known as the "Father of Waters," drains 40 percent of the continental United States and discharges an annual average flow of 640,000 cfs into the Gulf of Mexico. On the basis of drainage area and mean annual discharge, the Mississippi is the largest river in the United States (Iseri and Langbein, 1974) and is ranked by annual discharge as the sixth largest river in the world (Berner and Berner, 1996). Figure 12-1 highlights the location of the seven catalog units of Accounting Unit 070102 for the Upper Mississippi River case study in the vicinity of Minneapolis-St. Paul in Minnesota. The Twin Cities are one of the Nation's many major urban areas characterized by water pollution problems during the 1950s and 1960s (FWPCA, 1966; USPHS, 1951; 1953). Federal enforcement conferences were convened in 1964 and 1967 to investigate water pollution problems in the Minnesota and Wisconsin sections of the Upper Mississippi River (Zwick and Benstock, 1971).

In this chapter, data and information are presented to characterize long-term trends in population, municipal wastewater infrastructure and effluent loading of pollutants, ambient water quality conditions, environmental resources, and uses of the Upper Mississippi River in the vicinity of the Twin Cities. Data sources included STORET, EPA's national water quality database, USGS streamflow records (USGS, 1999a), published literature, unpublished data, newsletters, and technical reports obtained from the Metropolitan Council Environmental Services (MCES) in St. Paul and from other state, local, and federal agencies. Data have also been obtained from a validated water quality model of the Upper Mississippi River (Lung and Larson, 1995) to identify the progressive improvements in dissolved oxygen and other water quality parameters attributed to upgrades of the Metropolitan Wastewater Treatment Plant in St. Paul from primary to secondary and advanced secondary with nitrification (Lung, 1998).

The Twin Cities of Minneapolis and St. Paul are the major urban centers for more than 1,100 miles along the Mississippi River upstream of St. Louis, Missouri. About one-third of the population and a majority of the commercial and industrial activity of Minnesota are located within the Twin Cities metropolitan region. Outside the Twin Cities, the Upper Mississippi watershed is primarily rural and forested with the population dispersed in small towns and farms. The glaciated topography of the watershed provides extensive habitat for fish and wildlife and also supports an economy historically based on agriculture and wood products. In addition to these economic sectors, industrial and manufacturing activities have become significant components of the overall economy.

Physical Setting and Hydrology

The Upper Mississippi River basin (Hydrologic Region 7) covers a drainage area of 171,500 square miles over a reach of 1,170 miles from the headwaters in Lake Itasca to the confluence of the Missouri River with the Mississippi River at Alton, Illinois, just upstream of St. Louis, Missouri (Iseri and Langbein, 1974) (Figure 12-1). The water quality of the Upper Mississippi River has historically been dominated by wastewater loading from the Twin Cities, as well as sediments, nutrients, pesticides, oxidizeable materials, and other pollutants from the Minnesota River basin, the watershed of the Upper Mississippi River basin (Catalog Unit 07010206) described in this case study includes a drainage area of 8,520 square miles extending 83 miles from the confluence of the Crow River (UM milepoint 894) in Morrison County upstream of Anoka, Minnesota (Upper Mississippi milepoint 871) to the confluence of the St. Croix River downstream of Lock and Dam No. 2 at Prescott, Wisconsin (UM milepoint 811) (Figure 12-2).

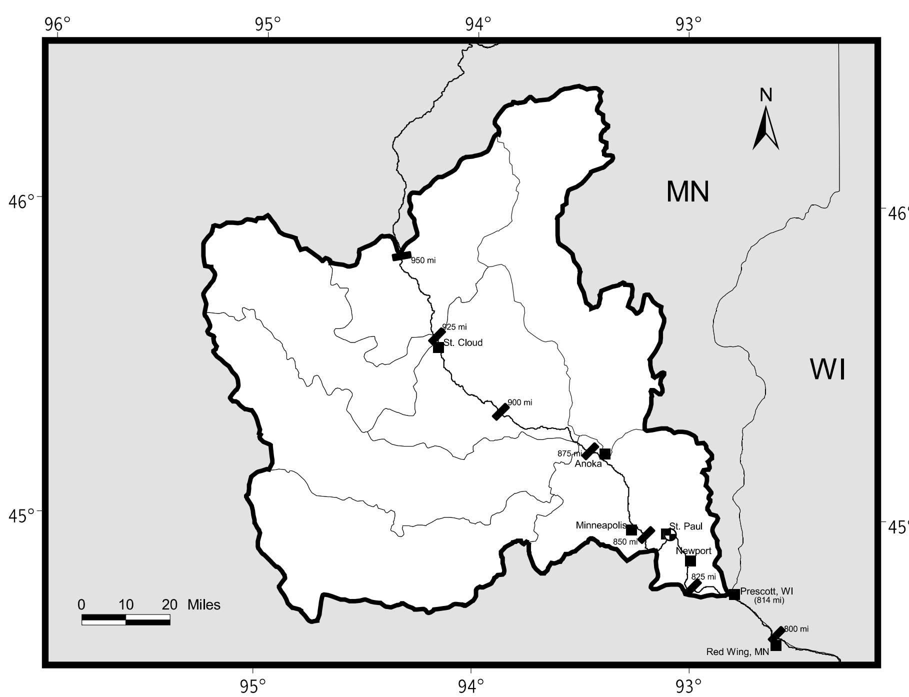


Figure 12-2

Location map of Upper Mississippi River (Accounting Unit 070102) near Minneapolis-St. Paul, Minnesota. River miles shown are distances from confluence of Mississippi River with Ohio River at Cairo, Illinois.

Characterized by rolling hills and plains with numerous lakes, the basin topography reflects the effects of successive glacial advances over the region. Upstream of the Twin Cities, the major tributaries to the Upper Mississippi are the Minnesota River, the Rum River at Anoka, and the Crow River. Within the portion of the watershed influenced by wastewater loading from the Twin Cities, five locks and dams have been constructed for flood control, navigation, and hydropower purposes. Because of the flow-regulating nature of the series of locks and dams, the river essentially flows as a series of controlled backwater pools with relatively constant surface elevations. Over the 69-mile reach from Coon Rapids Dam upstream of Minneapolis (UM river mile 866) to Lock and Dam No. 3 at Red Wing, Minnesota (UM river mile 797), the river drops from an elevation of 830 feet to 661 feet above mean sea level (Hydroscience, 1979).

The series of locks and dams, supplemented by dredging, maintain a 9-foot-deep navigation channel for commercial barge traffic. The navigation channel was authorized by the U.S. Congress in 1928, and the locks and dams were authorized in 1930. The U.S. Army Corps of Engineers is conducting a controversial environmental study is assessing the impact of the lock and dam system on the ecological integrity of the Upper Mississippi River. In addition to the ecological effects of the flow control structures, the Great Flood of 1993 (Wahl et al., 1993) has generated investigations of the role that artificial drainage and flood-control structures might have played in actually increasing the extent of severe flooding in some areas of the watershed.

On a seasonal basis, streamflow of the Upper Mississippi River reflects peak precipitation during late spring snowmelt and early summer with severe subfreezing winter conditions (Figure 12-3). Although the minimum flow occurs during winter due to a reduction in watershed runoff as precipitation changes from rain to snow and ice, the critical period for water quality problems is during the low-flow, summer months. On the river itself, winter ice cover is intermittent, varying considerably both spatially and temporally. Ponded areas of the Upper Mississippi River, such as Lower Pool 2 and Lake Pepin (Pool 4), have permanent ice cover for about 3 months during the winter; the more riverine reaches freeze over only during extended periods of severe cold. DO levels are generally

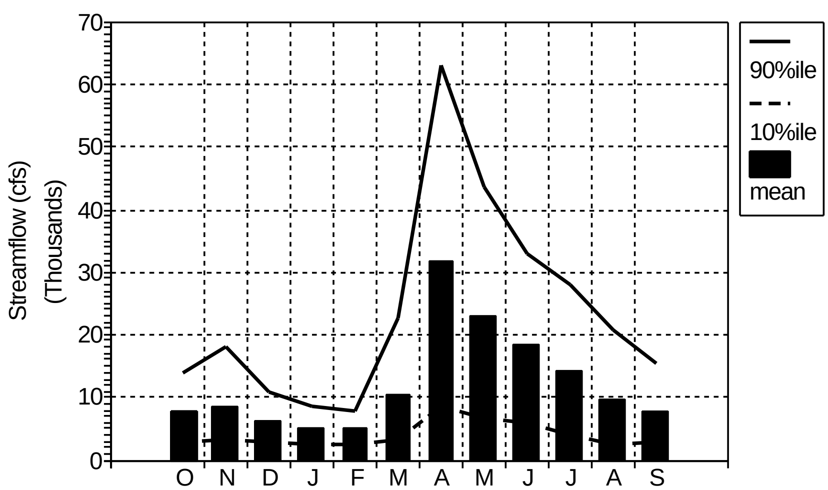


Figure 12-3

Monthly mean, 10th, and 90th percentile streamflow (1951-1980) at St. Paul, Minnesota, USGS Gage 05331000.

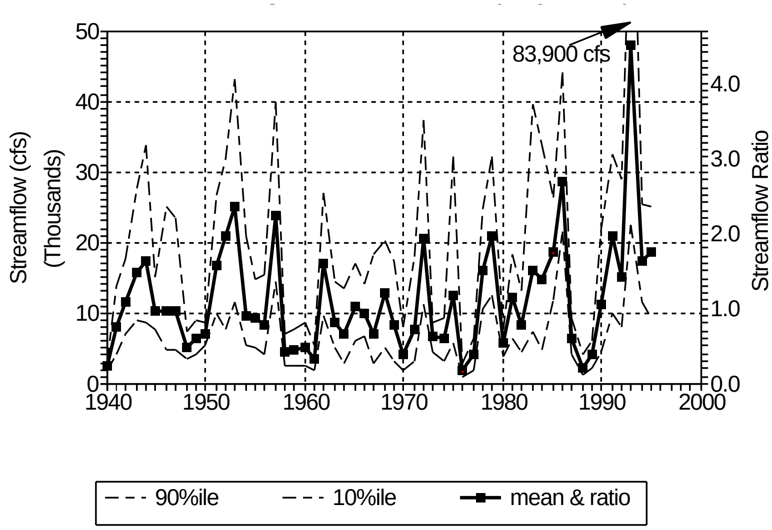
Source: USGS, 1999a.

high during winter because of very low water temperature and open water conditions that allow oxygen exchange across the air-water interface. Reliable streamflow records from a USGS gage 300 feet upstream of the Roberts Street Bridge in St. Paul (UM milepoint 839.3) are available from 1892 to the present to characterize long-term monthly, annual, and extreme flow statistics over a drainage area of 36,800 square miles (USGS, 1999a). Based on the historical data recorded for water years 1892-1998, monthly flow ranges from a maximum of 26,060 cfs in April to a winter minimum of 4,544 cfs during February and a summer low of 8,060 cfs during September. Over the period of record from 1892 to 1998, annual average discharge of the Upper Mississippi River at St. Paul has been 11,630 cfs, with the lowest daily mean flow of 632 cfs recorded on August 26, 1934, and the highest daily mean flow of 171,000 cfs observed on April 16, 1965 (USGS, 1999a). Using historical records from 1936-1979 to represent streamflow variability after the series of locks and dams were constructed on the Upper Mississippi River, the 7-day, 10-year flow (7Q10) for summer conditions (June-September) at St. Paul is reported as 1,633 cfs (MPCA, 1981).

The long-term (1940-1995) interannual variation of mean, 10th, and 90th percentile summer (July-September) streamflow is shown in Figure 12-4. The historical record exhibits pronounced year-to-year variability of summer streamflow. Based on data from 1951-1980, the long-term mean summer (July-September) flow of 10,659 cfs is used to compute a normalized streamflow ratio for each summer from 1940 to 1995 as dry (< 0.75), normal (0.75-1.50) or wet (> 1.50). For example, the summers of 1962, 1972, 1978-79, 1983, 1985-86, 1991, and 1993-95 were all characterized by wet conditions, where the flow was greater than 150 percent of the long-term summer mean. The summers of 1960-61, 1964, 1967, 1870-71, 1973-74, 1976-77, 1980, and 1987-89, in contrast, were characterized by dry conditions, where the flow was less than 75 percent of the long-term summer mean. The extreme droughts of 1976 (1,725 cfs, 16 percent of summer mean) and 1988 (2,334 cfs, 22 percent of summer mean) and the Great Flood of 1993 (47,789 cfs, 450 percent of summer mean) are particularly noticeable in the 55 years of historical records for the Upper Mississippi River at St. Paul.

Figure 12-4

Long-term trends of summer (July-September) mean, 10th, and 90th percentile streamflow at St. Paul, Minnesota, USGS Gage 05331000.



Population, Water, and Land Use Trends

Beginning in 1838 when the Twin Cities area was first opened for settlement, the abundant land and water resources attracted homesteaders. The confluence of the Minnesota River and the Upper Mississippi River served as an important transportation link between military and trading posts and the growing towns and cities along the Mississippi River. St. Anthony's Falls provided a natural source of power for lumber and grist mills. The fertile soil supported an agricultural economy, and the vast forests provided resources for a growing wood products industry. Uses for the Upper Mississippi River have included municipal and industrial water supply, commercial navigation, log transport, commercial fishing, hydropower, and water-based recreational activities. Beginning with the construction of an urban sewer system in 1871, the Upper Mississippi River has also been used for wastewater disposal.

As a component of the Lake Pepin Phosphorus Study, conducted from 1994 to 1998, historical records of land uses, agricultural practices (e.g., manure applications and commercial fertilizer uses), and wastewater discharges, compiled beginning ca. 1860, were used to correlate long-term changes in land uses in the watersheds of the Upper Mississippi River, the Minnesota River, and the St. Croix River with long-term changes in sediment and phosphorus loading to Lake Pepin (Mulla et al., 1999). As of the mid-1990s, the USGS (1999b) had classified about 60 percent of the watershed (Upper Mississippi River, Minnesota River, and St. Croix River) as agriculture and 23 as forest. The remaining 17 percent of the drainage basin was classified as urban and suburban (5 percent), water (5 percent), and wetlands (7 percent) (USGS, 1999b).

The Upper Mississippi River case study area includes a number of counties identified by OMB (1999) as a Metropolitan Statistical Area (MSA) (Table 12-1). Long-term trends in the population of the 13-county Minneapolis-St. Paul MSA are shown in Figure 12-5. Resident population in this MSA increased by 150 percent from 1.1 million in 1940 to 2.76 million in 1996. After a small increase of population from 1940 to 1950, the greatest rate of growth occurred during the 1950s and 1960s, when population increased by 23-27 percent. The rate of population growth then declined during the 1970s to 8.5 percent, with an increase to 15 percent during the 1980s. During the period from 1990 to 1996, population increased by 9 percent (Forstall, 1995; USDOC, 1998). Reflecting population growth in the Twin Cities area, the population served by the Metro plant increased from 1.04 million in 1962 to 1.68 million in 1997. By 2020, the plant is expected to provide service to 1.94 million people (Larson, 1999).

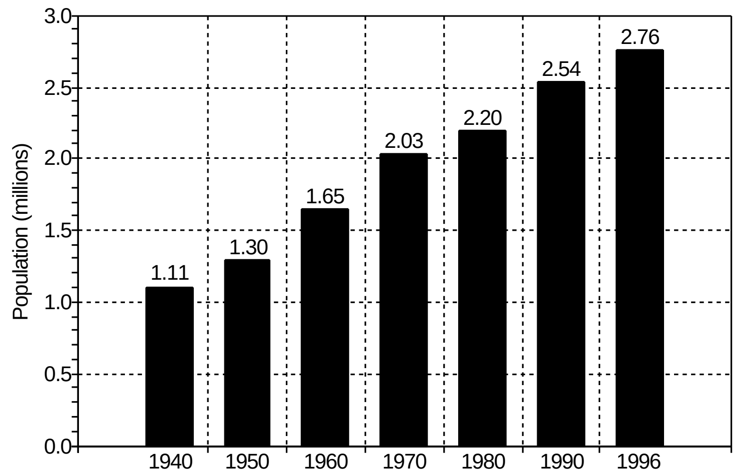
Table 12-1. Metropolitan Statistical Area (MSA) counties in the Upper Mississippi River case study. *Source: OMB, 1999.*

Anoka	Scott
Carver	Sherburne
Chicago	Washington
Dakota	Wright
Hennepin	Pierce
Isanti	St. Croix
Ramsey	

Figure 12-5

Long-term trends in population for the Minneapolis-St. Paul, MN-WI MSA counties for the Upper Mississippi River case study area.

Sources: Forstall, 1995; USDOC, 1998.



Historical Water Quality Issues

As with many other urban areas of the United States, the Upper Mississippi River was grossly polluted early in the 20th century because of growing urban populations and inadequately treated municipal and industrial wastewater discharges. Municipal officials simply relied on the natural flushing of rivers to dilute the human and industrial waste products of the growing metropolitan areas. City sewers, first constructed in 1871 in the Twin Cities, collected storm water and sewage and discharged them directly into the river. By the early 1900s, the Upper Mississippi River was unable to biologically assimilate the untreated wastewater collected from the Twin Cities (MWCC, 1988).

Before construction of a lock and dam in Minneapolis in 1917, annual peak spring flows maintained a minimally acceptable degree of water quality by the physical removal of raw sewage and other waste materials accumulated during the previous year in the Twin Cities area. Construction of the lock and dam, however, drastically altered this natural cycle by slowing the current of the river and reducing the flushing effect of the peak spring flows. By 1920, 3 million cubic yards of sewage sludge had accumulated in the pool created by the lock and dam. Water quality was severely degraded by depletion of dissolved oxygen from decomposition of the sludge bed. Bacteria levels were extremely high, sewage sludge mats floated on the surface, and the river was noxious from hydrogen sulfide gas caused by septic conditions during the warm summer months. The Upper Mississippi River was grossly polluted for a distance of 30 miles from St. Anthony's Falls in Minneapolis to the St. Croix River at Prescott, Wisconsin (MWCC, 1988).

A 1928 joint report by the Minnesota and Wisconsin State Boards of Health stated that *"a zone of heavy pollution extends from Minneapolis to the mouth of the St. Croix."* The state report pronounced *"the river in this zone . . . unfit for use as a water supply . . . fish life has been exterminated."* The report stated that the river was *"a potential danger from a health standpoint."* Beginning with a river survey in 1926, the State Board of Health documented DO levels of less than 1 mg/L over a 25-mile reach from St. Paul to Hastings, Minnesota, that could not support a healthy aquatic ecosystem, including pollution-tolerant carp (Mockavak, 1990). From 1926 to 1937, minimum DO levels of 1 to 2 mg/L indicated less than 10 percent of oxygen saturation over a 20- to 25-mile reach downstream from St. Paul (Wolman, 1971). Bacteria levels were also extremely high, with total coliform concentrations of 105 to 106 MPN/100 mL measured downstream of St. Paul (MRI, 1976). The extent of the public health risk incurred from the discharge of raw sewage by the Twin Cities was made painfully clear in 1935 when a failure of the chlorination units at the public water supply plant resulted in a serious typhoid epidemic with 213 cases and 7 deaths (USPHS, 1953).

In adopting the 1928 Board of Health recommendations, the Twin Cities became the first major city on the Mississippi River to implement primary treatment and chlorination for its municipal water pollution control plant in 1938. Water quality quickly improved dramatically as the floating mats of sludge disappeared, and DO levels increased to better than 3 mg/L from 1942 through 1955 (Mockovak, 1990; Wolman, 1971). Within 2 years fish returned and anglers reported catching walleye and other game fish in parts of the river that had been devoid of game fish prior to 1938. Maurice Robbins, a former deputy administrator of the Metropolitan Waste Control Commission (MWCC), recalled that *"The impact [of waste treatment] on the river was tremendous . . . no more dead fish, no more sewage smell"* (MWCC, 1988).

With increasing population (Figure 12-5), growth eventually overwhelmed the capacity of the river to assimilate the wastewater discharge from the primary Metro plant during the mid-1950s through the mid-1960s. Water quality once again deteriorated to conditions reminiscent of the 1920s and 1930s. During the summer of 1964, the Federal Water Pollution Control Administration (FWPCA) conducted a water pollution survey of the Upper Mississippi River that documented severe degradation of water quality (FWPCA, 1966). In contrast to an average of about 30,000 MPN/100 mL near St. Paul during the 1950s, total coliform densities ranged from 460,000 to 17,000,000 MPN/100 mL 9 miles downstream of St. Paul. Minimum DO levels of less than 1 mg/L were also recorded for 15 miles downstream of St. Paul. The biological health of the river abruptly changed, with a zone of degradation and decay extending 20 miles from St. Paul to Lock and Dam No. 2 at Hastings, Minnesota. The river bottom, thick with sewage sludge, was found to be devoid of the benthic organisms usually associated with clean waters (FWPCA, 1966; WRE, 1975).

In 1966 the Metro plant was upgraded to secondary treatment using the activated sludge process. Water quality once again improved, surpassing the 1928 guidelines. The rapidly growing suburban population, however, tended to generate more residual waste load than could be removed by upgrading the plant to secondary treatment. Regardless of the Metro plant upgrades, annual high spring flows caused flooding of the plant, resulting in the discharge of raw sewage into the river. During the late 1960s, only 4 of the 33 suburban treatment plants provided adequate levels of treatment, thus contributing to the overall pollution loading of the river. Minneapolis and St. Paul further contributed to periodic pollution loading to the river through a network of combined storm water and sewage collection sewers that discharged raw sewage during rainstorms.

In 1984 the Metro plant was upgraded once again to advanced secondary treatment with nitrification, designed to reduce effluent levels of ammonia. After implementation of secondary and advanced secondary waste treatment for the wastewater treatment plants of the Twin Cities area by the mid-1980s, water quality of the Upper Mississippi River routinely has been in compliance with water quality standards for dissolved oxygen and un-ionized ammonia. In contrast to the record of compliance for oxygen and un-ionized ammonia, turbidity levels have exceeded water quality objectives as a result of nonpoint source runoff of sediment from the Minnesota River basin (MWCC, 1994). Because the land uses of the Minnesota River basin are dominated by agricultural row crops and the fine-textured soils further contribute to sediment losses, the annual mean (1976-1996) sediment yield of 134 lb/acre-yr from the Minnesota River watershed is almost five times greater than the annual mean sediment yield of 28 lb/acre-yr estimated for the Upper Mississippi River basin upstream of Lock & Dam No. 1 (Meyer and Schellhaass, 1999). Fecal coliform levels also remained high and often violated state water quality standards through the mid-1980s because of combined sewer overflows during rainstorms. Fecal coliform bacteria samples are in compliance with Minnesota water quality standards if the monthly geometric mean is less than 200 MPN/100 mL and any individual sample does not exceed 2000 MPN/100 mL.

In 1984 it was estimated that 4.6 billion gallons per year of raw sewage and storm water were discharged to the Upper Mississippi River. In response to this water quality problem and public pressure, the Twin Cities implemented an aggressive $320 million (1996 dollars) construction program from 1985 to 1995 intended to accelerate the completion of the ongoing project to separate the combined sewers (MCES, 1996). As a result of the separation of storm water and raw sewage from the combined sewer system, fecal coliform bacteria levels have declined considerably, and compliance with state water quality standards has improved greatly at stations monitored at Lock and Dam No.1, St. Paul, Grey Cloud Island, and Pool 2 (Buttleman and Moore, 1999). Figure 12-6 shows the reduction in bacteria levels and the corresponding improvement in compliance with water quality standards. The monitoring station at St. Paul exhibits the greatest improvement, with compliance achieved at the 71 percent level for samples collected from 1996 to 1998. High bacteria levels, however, do occasionally occur in the heavily urbanized area upstream of Lock and Dam No. 1; the high levels apparently are associated with urban storm water runoff (Buttleman and Moore, 1999).

To remedy the periodic flooding of the Metro plant that resulted in the discharge of raw sewage to the river, flood protection projects were completed in 1975 and effluent pumps were installed in 1977. The pumps allowed the Metro plant to treat wastewater during the annual spring floods. The success of the flood control efforts at the Metro plant was dramatically demonstrated during the flood events of 1993 and 1997 when the plant recorded 100 percent compliance with NPDES permit limits during these two extreme events. Many other water pollution control plants in the region were forced to bypass waste treatment as a result of these extraordinary floods (Larson, 1999). In addition to their use for flood control, the effluent pumps are used during low-flow conditions when DO levels are depressed to aerate the effluent to increase ambient oxygen levels in the river.

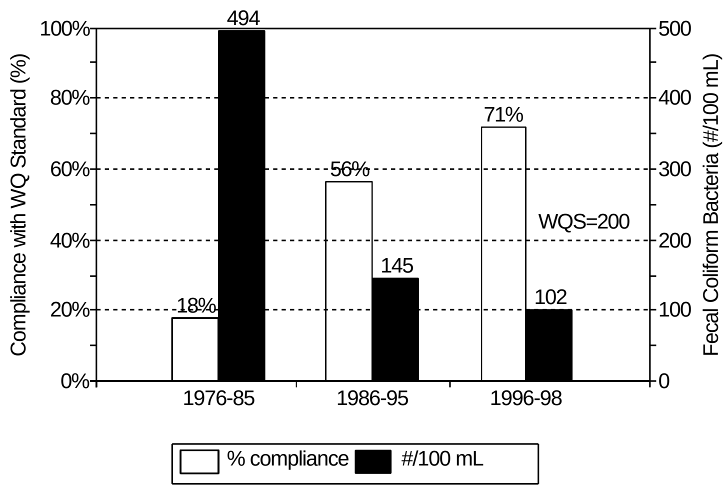


Figure 12-6

Pre- and post-CSO separation project trends in fecal coliform bacteria for the Upper Mississippi River at St. Paul. State standard for fecal coliform bacteria is 200 MPN/100 mL based on monthly geometric mean from May to October.

Source: Buttleman and Moore, 1999.

Responding to federal industrial pretreatment requirements promulgated in 1979, the Twin Cities initiated a program to reduce discharges of heavy metals to the Upper Mississippi River. A comprehensive strategy was adopted in 1981 to reduce the discharge of heavy metals from municipal water pollution control plants contributed by sanitary sewer discharges from industrial sources. By 1992, a decade after beginning the program, the loading of heavy metals to the river had been reduced by an average of 82 percent, with declines in ambient levels of heavy metals. Using sediment cores collected in Lake Pepin, Balogh et al. (1999) have reconstructed historical loading rates of mercury from ca. 1800 to 1996 from the Upper Mississippi River watershed to Lake Pepin (Figure 12-7). Averaging the sediment core data by 10-year intervals, Balogh et al. estimated a loading rate of 3 kg/yr to characterize naturally occurring deposition of mercury under pristine conditions before European settlement began ca. 1830. Mercury deposition progressively increased during the 19th and 20th centuries, with about one-half of the total mercury load deposited from 1940 to 1970 and the peak accumulation rate of 357 kg/yr identified during the 1960s. As a result of decreasing the discharges of mercury from municipal and industrial wastewater plants, the

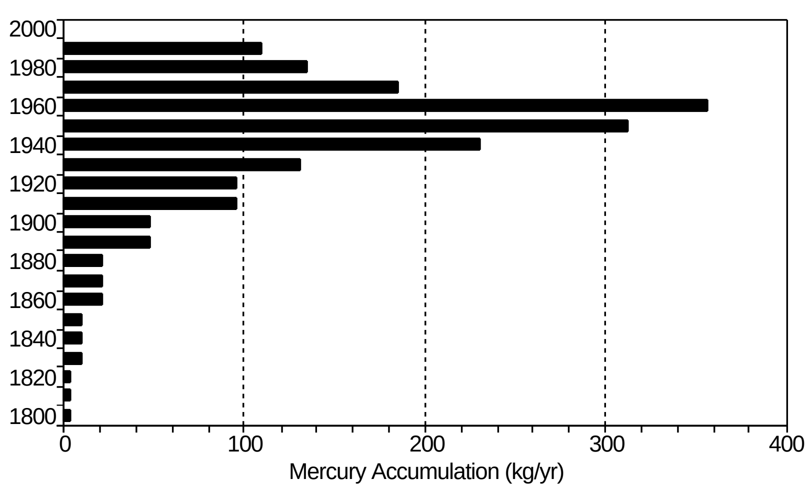


Figure 12-7

Historical mercury loading rates in the Upper Mississippi River reconstructed from sediments of Lake Pepin. Sediment core data averaged at 10-year intervals from 1800-1810 through 1980-1989 and 1990-1996.

Source: Balogh et al., 1999.

deposition rate in Lake Pepin has declined by almost 70 percent from the maximum loading during the 1960s to 110 kg/yr during 1990-1996. Although the investment in water pollution control has been very successful in reducing mercury in the Upper Mississippi River, ambient levels of mercury are still 30 times greater than the pristine conditions of the early 1800s (MCES, 2000). As of the late 1990s, the MCES is actively working to monitor and reduce even further the remaining sources of heavy metals, including mercury discharges to the river by wastewater treatment plants (MCES, 2000).

During the 1950s and 1960s, the depletion of dissolved oxygen in Pool 2 of the Upper Mississippi River near St. Paul adversely affected pollution-intolerant fish and other aquatic organisms. Studies during the early 1960s, for example, documented that burrowing mayflies (*Hexagenia*), an aquatic organism that is very sensitive to low DO conditions, were very scarce or absent from Pools 2 and 3 and Lake Pepin (Pool 4) of the river (Fremling, 1964). With the restoration of healthy levels of dissolved oxygen beginning in the mid-1980s, an abundance of mayflies once again colonized suitable habitats in the Upper Mississippi River from St. Paul to Lake Pepin after a 30-year absence from the river (Fremling and Johnson, 1990; MDNR, 1988). The resurgence of mayflies, significant improvements in ambient levels of DO and fecal coliform bacteria in Pool 2, and the reduction of mercury loading to the sediments of Lake Pepin demonstrate the successes of the water pollution control efforts implemented beginning in the 1980s. The Metro plant was upgraded to advanced secondary treatment with nitrification in 1984; the industrial pretreatment program was begun in 1982; and the accelerated CSO separation project, initiated in 1985 to jump-start an ongoing sewer separation project, was completed in 1995.

Legislative and Regulatory History

The Minnesota State Legislature passed an act in 1885 to prevent the pollution of rivers and other water supply sources. For the next 60 years, the Minnesota Board of Health had responsibility for water pollution problems. By 1907 the State Board of Health realized that consumption of drinking water contaminated by raw sewage discharges posed a serious public health threat. Without any authority, the Board of Health attempted to pressure the Twin Cities communities to install wastewater treatment facilities. In 1917 the State Board of Health adopted regulations requiring towns to submit plans for sewers and wastewater treatment plants prior to construction. The Board also conducted water pollution surveys and made various recommendations for controlling pollution. Letters to the city councils of the Twin Cities urging action on controlling the discharge of raw sewage went unanswered in 1923 and 1925. At the request of the State Board of Health, the U.S. Public Health Service conducted the first water pollution survey of the Upper Mississippi River from the Twin Cities to Winona, Minnesota, in 1926.

During the 1920s the Izaak Walton League, the Engineers Society of St. Paul, the Engineering Club of Minneapolis, and other private groups lobbied for immediate action on the problem of raw waste disposal into the river. In 1926 the Minneapolis Sanitary Commission was created to study *"the condition of the river and the problems of sewage disposal"* (MWCC, 1988). In 1927, when the Metropolitan Drainage Commission was formed, raw sewage was discharged through 84 outfalls over a network of 1,125 miles of sewers (MWCC, 1988). Maurice Robbins, a former deputy administrator of MWCC, remembering his experiences sampling the river during those years, stated that *"It could get pretty awful down by the river. There were floating feces, dead fish and a terrible sewer smell"* (MWCC, 1988).

In 1927 the State Board of Health was given the authority and the responsibility to administer and enforce all laws related to water pollution in Minnesota. The legislature directed the State Board of Health to form a Metropolitan Drainage Commission. The legislature, however, did not provide any substantial basis for managing waste disposal. In 1933, a decade after the Minnesota State Board of Health had begun to document the pollution problems of the Upper Mississippi River, the Minneapolis-St. Paul Sanitary District was finally created to oversee construction of the first primary wastewater treatment plant in the Twin Cities region. The primary treatment plant, located near Pig's Eye Lake in St. Paul, went online in 1938.

In 1945 the legislature passed the Water Pollution Control Act to establish the Water Pollution Control Commission for the regulation of the emerging problems of water pollution. The Minnesota Act, amended in 1951, 1959, and 1963, was regarded as one of the better water pollution control acts in the United States (FWPCA, 1966). The main mission of the new Water Pollution Control Commission was to direct the construction of primary wastewater treatment plants for the smaller municipalities in the Twin Cities metropolitan area.

In 1967 the state legislature formed the Metropolitan Council as a regional coordination agency. In 1969 the Metropolitan Waste Control Commission (MWCC) was given the regional responsibility for wastewater collection and treatment systems for 33 plants within 200 political jurisdictions of the seven-county Twin Cities area. In 1967 the legislature also created the Minnesota Pollution Control Agency (MPCA) to replace the Water Pollution Control Commission. The new agency was soon given authority to regulate and enforce effluent limits for municipal and industrial treatment plants. The establishment of the U.S. Environmental Protection Agency and the enactment of the 1972 Clean Water Act further strengthened the regulatory powers for requiring uniform effluent limits for wastewater dischargers. In July 1994 the MWCC and transit services were merged with the Metropolitan Council. The responsibility for operating municipal wastewater treatment plants was delegated to the Environmental Services Division of the Metropolitan Council (MCES).

Following the 1972 Clean Water Act, the MWCC, with federal (75 percent) and state (15 percent) funding assistance, spent more than $350 million to dramatically improve the technology of the Metro plant, upgrade other facilities, and build interceptor sewer systems (MWCC, 1988). During the 1970s and 1980s, MWCC phased out or upgraded old plants or constructed new plants for many of the suburban communities in the Twin Cities region. MCES now operates the Metro plant and eight other treatment plants in the Twin Cities area. The Metro plant and three other wastewater treatment plants discharge to the Upper Mississippi River; three plants discharge effluent to the Minnesota River; and the St. Croix River and the Vermilion River each receive effluent discharges from one municipal plant.

Impact of Wastewater Treatment: Pollutant Loading and Water Quality Trends

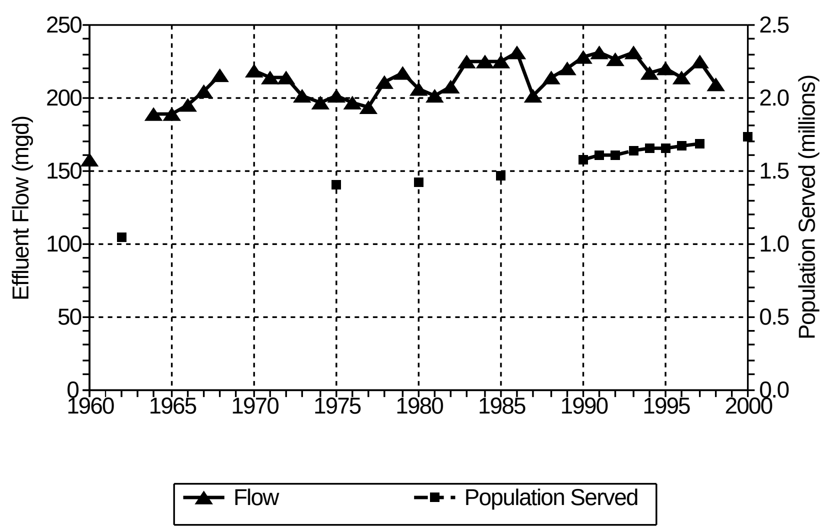
During the 1960s and 1970s, effluent loading from the Metro plant accounted for more than three-quarters of the total point source load of BOD_5 in the section of the Upper Mississippi River from the Twin Cities to the St. Croix River. Because this one wastewater treatment plant, the Metro plant, accounted more than 75 percent of the total point source load, historical effluent data from the Metro plant can serve as an indicator to demonstrate the success of public investments to upgrade the plant in improving water quality in the Upper Mississippi River. Figures 12-8 through 12-11 present time-series trend data for population served, effluent flow, BOD_5, total suspended solids (TSS), total Kjeldahl nitrogen (TKN), and ammonia loading for the Metro plant (Larson, 1999).

During the early 1960s, the Metro plant served 1.05 million people and discharged 158 mgd to the Upper Mississippi River. By 1997 the population served by Metro had grown to 1.7 million with a corresponding increase in the effluent discharge rate to 225 mgd (Figure 12-8). Since enactment of the Clean Water Act in 1972, effluent BOD_5 loading from the Metro plant has been reduced greatly from the peak loading period of the mid-1960s. Before upgrading the Metro plant, effluent BOD_5 loading peaked at about 330,000 lb/day in 1968. After upgrading to secondary in 1966, effluent loading dropped to 114,000 lb/day by 1970 and 77,000 lb/day in 1973. Since the 1980s, effluent loading of BOD_5 has continued to decline as a result of additional upgrades (e.g., advanced secondary in 1984) and replacement, or abandonment, of 21 of the 33 suburban wastewater treatment plants that existed in 1969 when MWCC assumed responsibility for plant operations. BOD_5 loading from Metro declined again to 40,000 lb/day by 1980 and to 27,000 lb/day by 1990 (Figure 12-9). Over a 30-year period, upgrades and improvements to the Metro plant have reduced effluent BOD_5 loading by 95 percent from the historical peak loading of 330,000 lb/day in 1968 to only 17,000 lb/day in 1998. Over the same period, the effluent concentration of BOD_5 has been reduced from 184 mg/L in 1968 to 9.7 mg/L in 1998.

Figure 12-8

Long-term trends in population served and effluent flow for the Metro plant in St. Paul.

Source: Larson, 1999.



Upgrades and improvements to the Metro plant have also resulted in large reductions in effluent loading of suspended solids and nitrogen. TSS loading has dropped by 95 percent from the peak loading rate of 219,000 lb/day in 1968 to 10,000 lb/day by 1998; effluent concentration declined from 122 mg/L in 1968 to 5.7 mg/L by 1998 (Figure 12-10). Based on effluent data from monitoring that began in 1971, TKN loading has dropped by 78 percent from the peak loading rate of 36,500 lb/day in 1982 to 7,800 lb/day by 1998; effluent concentration has been reduced from 21 mg/L in 1982 to 4.5 mg/L by 1998 (Figure 12-11). Prior to the upgrade to advanced secondary with nitrification, toxicity-based water quality standards for the un-ionized portion of ammonia were frequently violated in the Upper Mississippi River. After upgrading the plant to nitrification with ammonia removal in 1984, effluent discharges of ammonia declined considerably. Using effluent data collected since 1975, ammonia nitrogen (NH_3-N) loading has dropped by 90 percent from the peak loading rate of 25,500 lb/day in 1982 to 2,600 lb/day by 1998. The effluent concentration of ammonia has been reduced from 14.7 mg/L in 1982 to 1.5 mg/L by 1998 (Figure 12-11).

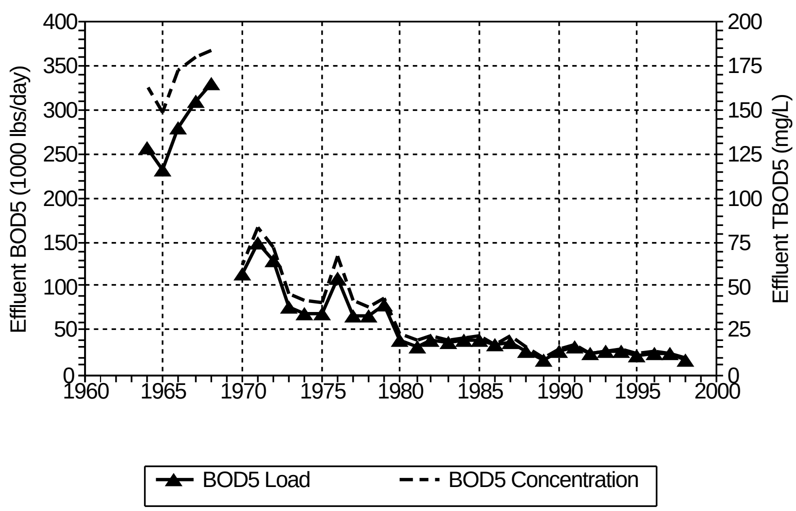


Figure 12-9

Long-term trends in effluent loading of BOD_5 for the Metro plant in St. Paul.

Source: Larson, 1999.

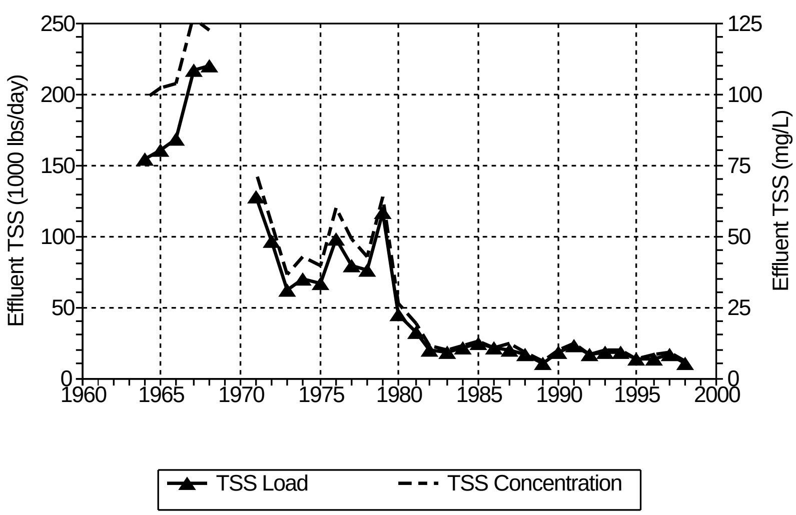


Figure 12-10

Long-term trends in effluent loading of TSS for the Metro plant in St. Paul.

Source: Larson, 1999.

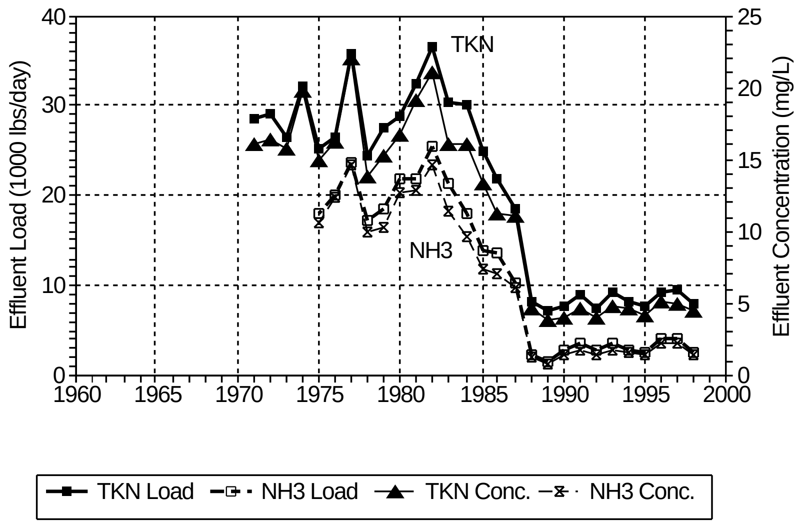


Figure 12-11

Long-term trends in effluent loading of TKN and ammonia-N for the Metro plant in St. Paul.

Source: Larson, 1999.

Beginning in the 1920s through the 1970s, the major water quality issues for the Upper Mississippi River have been bacterial contamination and depletion of DO from sewage discharges and combined sewer overflows. Historical DO data sets collected since 1926 illustrate the dramatic change in long-term trends in the spatial distribution of DO recorded 5 miles downstream of the confluence with the Minnesota River near St. Paul (UM milepoint 840) to Lock and Dam No. 3 at Red Wing, Minnesota (UM milepoint 797) (Figure 12-12). These historical data sets clearly illustrate the adverse impacts of wastewater loading and the effectiveness of upgrades in wastewater treatment implemented in 1938, 1966, and the early 1970s at the Metro plant. Because of the hydraulic characteristics of the Upper Mississippi River, minimum DO levels have been consistently observed in a zone 5 to 15 miles downstream of the Metro plant discharge, within the oxygen sag region from Newport (UM milepoint 820) to Grey Cloud (UM milepoint 830).

Using historical data available from EPA's STORET water quality database, the long-term trend of summer DO and BOD_5 (1940-1995) has been compiled from monitoring station records extracted for RF1 reach 07010206001 from the Minnesota River (UM milepoint 844.7) to the St. Croix River (UM milepoint 811).

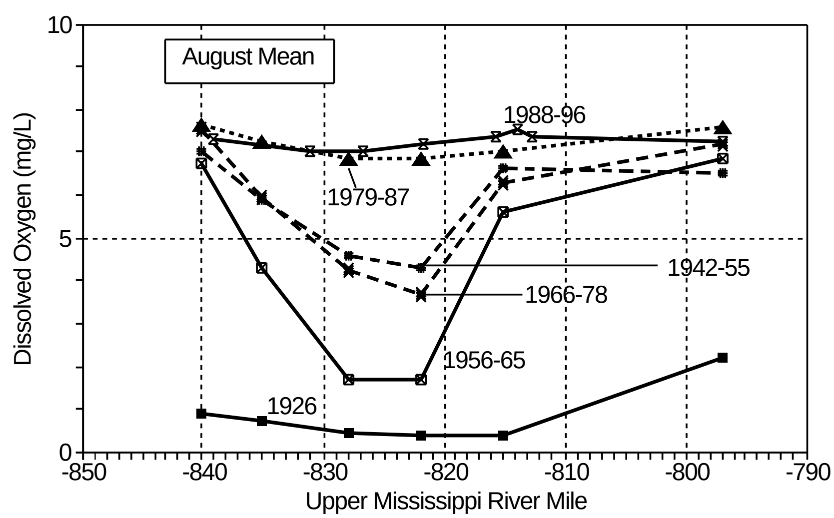


Figure 12-12

Spatial trends of August DO in the Upper Mississippi River from 1926 to 1988-96 from St. Paul (UM milepoint 840) to Lock & Dam No. 3 at Redwing (UM milepoint 797).

Sources: Larson, 1999; Mockovak, 1990; MWCC, 1989; Johnson and Aasen, 1989.

Although DO is characterized by a high degree of interannual variability because of temporal variability in streamflow and the spatial gradient over this 34-mile-long reach, there has been a definite improvement in this long reach between the 1960s when summer mean oxygen levels ranged from approximately 4 to 7 mg/L to the period from the mid-1970s through the mid-1990s when summer mean oxygen levels consistently ranged from approximately 7 to 8 mg/L even during the drought conditions of 1987-1988 (Figure 12-13). The trend of improvement in DO during the 1980s and 1990s is consistent with the long-term trend of improvement in ambient BOD_5 extracted for the same reach (Figure 12-14). During the 1960s and 1970s, summer mean BOD_5 ranged from approximately 4 to 8 mg/L. During the 1980s mean BOD_5 ranged from approximately 2.5 to 4.5 mg/L. In the period 1990-1995, mean ambient BOD_5 declined even further to levels ranging from approximately 2 to 3.5 mg/L as a result of upgrading the Metro plant to advanced secondary with nitrification in the late 1980s.

In interpreting the year-to-year variability of the long-term DO data from 1940 through 1995, it is important to understand the influence of streamflow on summer oxygen levels under the peak effluent loading conditions of the 1960s and

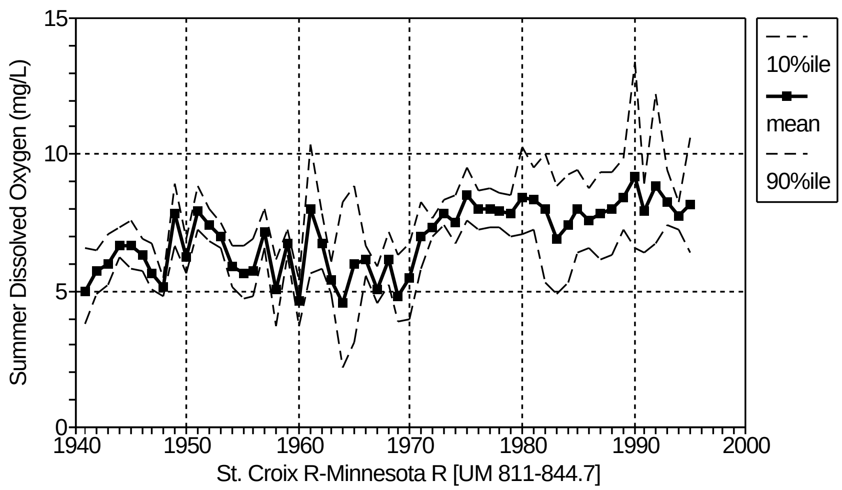


Figure 12-13

Long-term trends of mean, 10th percentile, and 90th percentile summer DO in the Upper Mississippi River for RF1 reach 07010206001 from the Minnesota River (UM milepoint 844.7) to the St. Croix River (UM milepoint 811).

Source: USEPA (STORET).

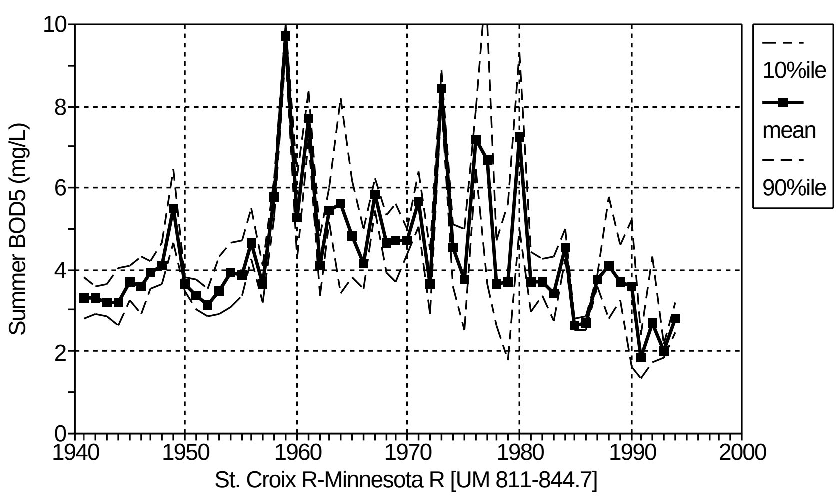


Figure 12-14

Long-term trends of mean, 10th percentile, and 90th percentile summer BOD_5 in the Upper Mississippi River for RF1 reach 07010206001 from the Minnesota River (UM milepoint 844.7) to the St. Croix River (UM milepoint 811).

Source: USEPA (STORET).

early 1970s compared to the greatly reduced effluent loading conditions that have characterized the Twin Cities area since the mid-1970s. Under conditions of similar effluent loading rates, DO decreases during low-flow conditions in contrast to a relative increase during higher summer flow conditions. Over years of comparable effluent BOD_5 loading, the interannual cycles that appear to show trends of either "improvement" or "degradation" in DO (Figure 12-13) are caused primarily by year-to-year variability of summer streamflow (see Figure 12-4). An accurate evaluation of the long-term trend in improvement of DO is possible only by filtering the time series of oxygen records to extract only those summers that are characterized by dry streamflow conditions.

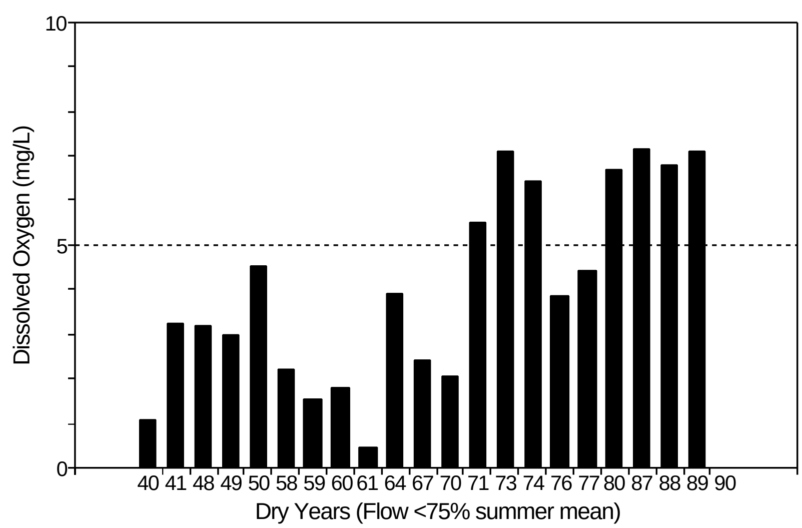
Figure 12-15 shows long-term trends in DO conditions for “dry” summers for a subreach of the RF1 reach 07010206001 for the critical oxygen sag location from Newport (UM milepoint 820) to Grey Cloud (UM milepoint 830). The time series record of DO data in Figure 12-15 is extracted to highlight the trend in improvement for summers of comparable “dry” streamflow conditions when the flow at the St. Paul USGS gage was less than 75 percent of the long-term (1951-1980) summer mean. During the 1960s, low-flow summer mean DO levels violated water quality standards with concentrations as low as less than 1 mg/L in 1961 to approximately 4 mg/L in 1964. After the upgrade of the Metro plant to advanced secondary with nitrification in the late 1980s, mean summer DO levels in the critical subreach had improved to levels as high as approximately 6 to 7 mg/L even during the extreme drought conditions of 1987-1988. Using before and after data in a postaudit model applied to the low-flow summers of 1976 and 1988, Lung (1996a) has clearly demonstrated that the improvements in DO can be directly related to upgrades of the Metro plant.

As shown by the historical records for fecal coliform bacteria (Figure 12-6), DO (Figure 12-15), and levels of sediment mercury in Lake Pepin (Figure 12-7), investments in water pollution control programs of the 1970s and 1980s have succeeded in improving water quality conditions for these historical problems of the 1950s, 1960s, and 1970s in the Upper Mississippi River. During the 1980s and 1990s, water quality and comprehensive ecological investigations in the Upper Mississippi River have identified a number of contemporary chemical and

Figure 12-15

Long-term trends of mean summer DO in the Upper Mississippi River for years characterized by "dry" streamflow conditions less than 75 percent of long-term (1951-1980) summer mean streamflow. Data extracted for subreach from Newport to Grey Cloud (UM milepoint 820-830).

Source: USEPA (STORET).



nonchemical problems in the basin. Nonchemical issues identified as threats to the ecological processes of the river and floodplain ecosystem include, for example, loss of habitat and wetlands and man-made alterations from flood control and navigation projects. Contemporary chemical problems include inputs of nutrients, sediments, heavy metals, pesticides, and other toxic chemicals.

For example, the loading of phosphorus and suspended solids influences water quality in Lake Pepin, a natural impoundment located about 50 miles downstream of St. Paul. Lake Pepin is eutrophic, with high annual mean concentrations of total phosphorus (0.16 mg/L) and soluble reactive phosphorus (SRP) (0.07 mg/L) (James et al., 1996) recorded at the inlet to the lake (UM milepoint 797) during the average flow years of 1994-1996. Eutrophic conditions in the lake are caused by excessive loading of nutrients from point and nonpoint sources in the watershed. When physical and hydrological conditions are favorable, such as during low-flow summers, nuisance algal blooms (i.e., viable chlorophyll *a* greater than 30 µg/L) occur. Concerns related to the need for controls on phosphorus loading arose after severe algal blooms and fish kills in Lake Pepin occurred under the drought conditions of 1987-1988 (Johnson, 1999).

The Lake Pepin Phosphorus Study, conducted from 1994-1998, compiled historical and contemporary data sets to evaluate the human impact on (1) long-term records of sediment and phosphorus loading to Lake Pepin and (2) the corresponding water quality responses to changes in loading to the lake. Since European settlement ca. 1830s, the contemporary (1990-1996) annual input of approximately 850,000 metric tons/year of sediment is about ten times greater than the loading rates estimated for the pre-settlement era. Analysis of data from the three basins included in the study, the Upper Mississippi River, the Minnesota River and the St. Croix River, indicates that 90 percent of the increased sediment load to Lake Pepin is contributed by erosion of fine-textured soils from the Minnesota River basin. The record of sediment deposition in Lake Pepin also indicates that the most rapid rates of sediment input to the lake occurred during the 1940s and 1950s. If current sedimentation rates continue from erosion in the Minnesota River basin, Lake Pepin could be completely filled in about 340 years (Engstrom and Almendinger, 1998).

Over the past two centuries, phosphorus concentrations in the sediments of Lake Pepin have increased twofold while water column concentrations (inferred from diatom assemblages in the sediments) appear to have increased by a factor of 4 since European settlement ca. 1830s. Increased phosphorus levels in the sediments and water column are the result of an increase in phosphorus loads to Lake Pepin by a factor of 5 to 7 since the 1830s to the contemporary estimated loading rate of approximately 4,000-5,000 metric tons/year for 1990-1996. Wastewater discharges and agricultural applications of manure and commercial fertilizer are most likely the key factors controlling historical phosphorus loads to Lake Pepin, and the statewide ban on phosphates in detergents contributed to a reduction in phosphorus loading from municipal wastewater plants by approximately 40 percent over the period from 1970 to 1980. Since the 1830s era, the progressive increase in phosphorus loading has resulted in a shift in assemblages of diatoms from clear water benthic algae and mesotrophic water column species in the pre-settlement era to planktonic species exclusively characteristic of highly eutrophic conditions in the 1990s (Engstrom and Almendinger, 1998).

In evaluating strategies to reduce phosphorus loads to Lake Pepin, the significant differences in the relative contributions of point and nonpoint sources of flow, solids, and nutrient loads under a range of flow conditions need to be considered over a time scale of decades. Point and nonpoint source loading data for suspended solids and total phosphorus have been compiled for low-flow (1988), average-flow (1994-1996) and high-flow (1993) conditions for the Upper Mississippi River (upstream of Lock and Dam No. 1), the Minnesota River, and the St. Croix River (Meyer and Schellhaass, 1999). Based on 21 years of data (1976-1996), the mean yield of total phosphorus from the agriculturally dominated Minnesota River (0.33 lb/acre-yr) is twice as great as the mean yield from the Upper Mississippi River basin upstream of Lock and Dam No. 1 (0.16 lb/acre-yr) and the St. Croix River basin (0.14 lb/acre-yr). Figure 12-16 presents a comparison of the magnitude of point source loads and nonpoint source loads of total phosphorus from the Upper Mississippi River, Minnesota River, and St. Croix River basins for 1988 (drought), 1993 (flood) and 1994-1996 (average conditions) (Meyer and Schellhaass, 1999).

Under the extreme flood conditions of 1993, nonpoint source loadings of total phosphorus from the Minnesota River and the Upper Mississippi River watersheds have been shown to account for 58 percent and 15 percent, respectively, of the total phosphorus load of 6,030 metric tons/yr estimated for 1993 while point sources from the Metro plant accounted for 15 percent of the total phosphorus load. During the severe drought conditions of 1988, the total phosphorus load of 1,900 mt/yr was only about one-third of the 1993 load. Under the drought conditions, the Metro plant accounted for 47 percent of the total phosphorus load and nonpoint source loading from the Minnesota River and the Upper Mississippi River contributed only 6 percent and 3 percent, respectively, of the total phosphorus load of 1,900 mt/yr. During the average flow conditions of 1994-1996, the total phosphorus load of 3,800 mt/yr was two times greater than the 1988 drought load. Under average flow conditions, the Metro plant accounted for 28 percent of the total phosphorus load and nonpoint source loading from the Minnesota River and the Upper Mississippi River contributed 38 percent and 14 percent, respectively, of the total phosphorus load of 3,800 mt/yr.

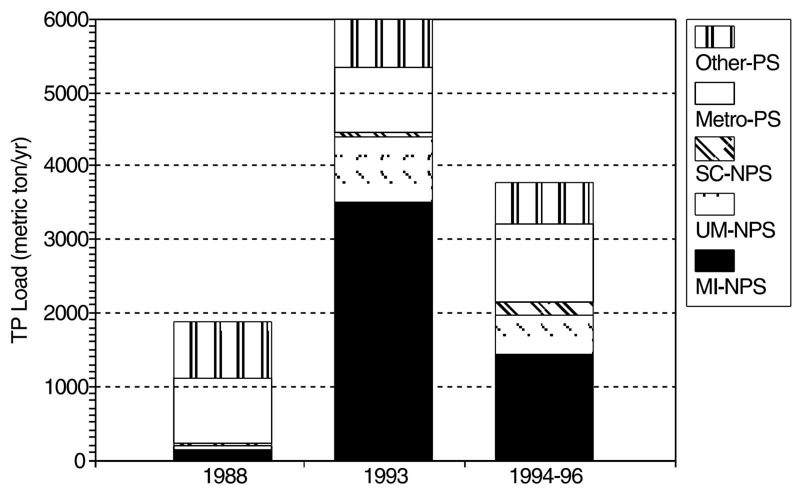


Figure 12-16

Comparison of total phosphorus loadings from nonpoint sources (NPS) in the Upper Mississippi River (UM, to Lock & Dam No. 1), Minnesota River (MI), and St. Croix River (SC) basins and point source (PS) loadings from the Metro plant and other facilities in the three river basins.

Source: Meyer and Schellhaass, 1999.

Meyer and Schellhaass (1999) have used this data set to develop summary budgets of the relative contributions of point source and nonpoint source loadings of total phosphorus to the three river basins during 1988, 1993, and 1994-1996. Under the drought conditions of 1988, the contribution from point sources (88.5 percent) dominated the total inputs of phosphorus compared to the 11.5 percent accounted for by nonpoint sources. During the extreme flood conditions of 1993, nonpoint source loads accounted for about three-quarters (74.5 percent) of the total input of phosphorus, with point sources accounting for about one-quarter (25.5 percent). During the average flow conditions of 1994-1996, the relative contribution of point sources (56.2 percent) and nonpoint sources (43.8 percent) was almost comparable.

These point source loading and nonpoint source loading data sets for suspended sediments and phosphorus and a number of other field studies (e.g., James et al., 1999) have been used to support the development of an advanced model of sediment transport and eutrophication for the Upper Mississippi River and Lake Pepin (HydroQual, 1999a, 1999b). As of 2000 the MCES is using the model to evaluate the effectiveness of alternative strategies to control point and nonpoint phosphorus loading to the Upper Mississippi River to achieve the water quality objectives established for Lake Pepin. Evaluations of sediment loading contributed primarily from agricultural runoff in the Minnesota River basin have also been a key issue in the Minnesota River Assessment Project (MPCA, 1994).

On the much larger scale of the entire Mississippi River basin, nitrogen loading from the Mississippi River has been identified as a major cause of the algal blooms and hypoxia that occur over a 16,000-square-kilometer area of the inner Gulf of Mexico known as the "Dead Zone" (Christen, 1999; Malakoff, 1998; Moffatt, 1998; Rabelais et al., 1996; Vitousek et al., 1997). Based on technical assessments of the "Dead Zone" problem, a U.S. EPA and NOAA Action Plan, expected to be released in August 2000, will most likely recommend that efforts be undertaken to reduce inputs of nitrogen from wastewater treatment plants and agricultural land uses (e.g., fertilizer applications and confined animal feedlots) over the entire Mississippi River basin, which drains 40 percent of the land area of the continental United States (Christen, 1999).

The series of locks and dams and maintained navigation channel have been an integral physical feature of the Upper Mississippi River since the early 1930s when the U.S. Congress authorized the U.S. Army Corps of Engineers to maintain the river for navigation purposes. Concerns have been raised about the disposal of dredged sediments, often contaminated with heavy metals and toxic chemicals, to maintain the navigation channel and the loss of ecologically critical backwater habitats to sediment deposits. The devastation caused by the Great Flood of 1993 (Wahl et al., 1993) in the upper Midwest has also triggered debates about the failure of flood control measures intended to protect river communities from floods. As the key federal agency responsible for inland waterways, the U.S. Army Corps of Engineers has initiated controversial studies to evaluate the ecological impact of maintenance dredging, flood control structures, and widening the series of locks and dams (Phillips, 1999).

Evaluation of Water Quality Benefits Following Treatment Plant Upgrades

From a policy and planning perspective, the central question related to the effectiveness of the secondary treatment requirement of the 1972 CWA is simply *Would water quality standards for DO be attained if primary treatment levels were considered acceptable?* In addition to the qualitative assessment of historical data, water quality models can provide a quantitative approach to evaluate improvements in dissolved oxygen and other water quality parameters achieved as a result of upgrades to secondary and greater levels of wastewater treatment. Since the 1970s, increasingly complex models have been developed to determine wasteload allocation requirements for municipal and industrial dischargers to meet the needs of decision-makers for the Upper Mississippi River.

During the mid-1970s the National Commission on Water Quality (see NCWQ, 1976) funded Water Resources Engineers (WRE) to develop a steady-state, one-dimensional water quality model (QUAL-II) of DO, BOD_5, nutrients, and fecal coliform bacteria using data collected in the Upper Mississippi River in 1964-1965 (FWPCA, 1966). The model was applied to evaluate the effectiveness of the technology-based requirements of the 1972 Clean Water Act for municipal and industrial dischargers. With funding available from the CWA Section 208 program, Hydroscience (1979) developed a water quality model (AESOP) of DO, BOD_5, nutrients, algae, and bacteria using data collected in 1973, 1976 and 1977. The model, further validated by the Minnesota Pollution Control Agency using data obtained in 1980, was used for a wasteload allocation study of the Metro plant's impact on DO and un-ionized ammonia in Pool 2 (MPCA, 1981).

As a result of the severe algal blooms and fish kills that occurred in Lake Pepin during the extreme drought of 1988, a time-variable water quality model (WASP5-EUTRO5) of DO, BOD_5, nutrients, and algae was developed using data collected during 1988 (MWCC, 1989), 1990, and 1991 (EnviroTech, 1992, 1993; Lung and Larson, 1995). The validated model was used to evaluate alternatives for phosphorus controls at the Metro plant and to perform a post-audit of the Hydroscience (1979) AESOP model using low-flow data collected during 1988 (Lung, 1996a). The model was also applied to track the fate and transport of phosphorus and the relative impact of the point and nonpoint sources on eutrophication in Lake Pepin (Lung, 1996b).

Following completion of the model by EnviroTech (1992, 1993), a number of uncertainty issues were identified related to (1) fate and transport of phosphorus from point and nonpoint sources; (2) interaction of suspended solids with phosphorus transport; and (3) interaction of nonpoint source phosphorus inputs generated under low-flow and high-flow hydrologic conditions with interannual variation in the benthic release of phosphorus. To address these issues, a three-dimensional hydrodynamic, sediment transport, and advanced eutrophication model was developed and calibrated using data collected over 12 years from 1985 through 1996 (Garland et al., 1999; HydroQual, 1999a, 1999b). The calibrated model was used to simulate the long-term (24-year) water quality response in the Upper Mississippi River and Lake Pepin to a number of alternative control scenarios over a range of hydrologic (e.g., dry and wet years) and loading conditions for point source and nonpoint source discharges of phosphorus.

To evaluate the incremental improvements in water quality conditions that have been achieved by upgrading municipal wastewater plants from primary to secondary and from secondary to advanced secondary levels of waste treatment, Lung (1998) used the WASP5-EUTRO5 model developed by EnviroTech (1992, 1993) to demonstrate the water quality benefits attained by the secondary treatment requirements of the 1972 CWA. Using the model, municipal and industrial wastewater flow and effluent loading data were used with boundary flow and loading data describing the Upper Mississippi River and Minnesota River to compare water quality conditions for three summers (1964, 1976, and 1988) characterized by comparable low-flow conditions and primary (1964), secondary (1976), and advanced secondary (1988) levels of wastewater treatment at the Metro plant. The model was applied to evaluate the water quality impact of three different treatment levels for Metro and the other municipal plants: (1) primary, (2) secondary, and (3) advanced secondary with nitrification. CBOD oxidation rates were calibrated for each of these three different data sets to reflect differences in the proportion of labile and refractory oxidizeable material discharged from the Metro plant.

A comparison of the results of the model runs and observed data sets is presented in Figure 12-17. Spatial distributions of CBOD-ultimate, ammonia-N, nitrate+nitrite-N, algal chlorophyll, and DO are presented from St. Paul (UM milepoint 840) to Lock & Dam No. 2 (UM milepoint 815) for 1964 (primary), 1976 (secondary), and 1988 (advanced secondary with nitrification). The upgrade of the Metro plant from primary to secondary and the corresponding reduction of effluent BOD_5 loading (see Figure 12-9) is reflected in the decrease in ambient CBOD from a peak of approximately 20 mg/L in 1964 to approximately 7 to 8 mg/L in 1976 at UM milepoint 835 near the Metro plant. As shown in the simulation results, the distributions of ammonia-N and nitrate+nitrite-N are similar under the primary and secondary treatment scenarios because upgrading from primary to secondary treatment does not change the effluent concentration of ammonia. The progressive reduction in ambient ammonia-N and corresponding increase in ambient nitrate+nitrite-N for the 1988 simulation, however, reflect the impact of the upgrade from secondary to advanced secondary with nitrification and the drop in effluent loading of ammonia-N at the Metro plant (see Figure 12-11). During the 1960s when Metro discharged primary effluent, a large section of the river was hypoxic or anoxic, with the worst conditions (< 2 mg/L) observed over approximately 15 miles from UM milepoint 820 to UM milepoint 835. The observed data and the model results indicate the elimination of anoxic conditions and a nominal improvement in DO conditions under the extreme low-flow conditions of August 1976. The minimum DO level is increased from approximately 0.5 mg/L in 1964 to approximately 2 mg/L in 1976 as a result of the upgrade from primary to secondary treatment. Even with secondary treatment at Metro, however, compliance with the water quality standard for dissolved oxygen of 5 mg/L was not achieved and a distinct oxygen sag is observed in the 1976 data set. Compliance with the DO standard was finally achieved, even under the extreme drought conditions of 1988, after Metro was upgraded from secondary to advanced secondary treatment with nitrification.

The model results demonstrate very clearly the progressive increase in DO levels in the river following the upgrades at Metro to secondary and advanced secondary treatment. The model results also demonstrate the ability of a well-

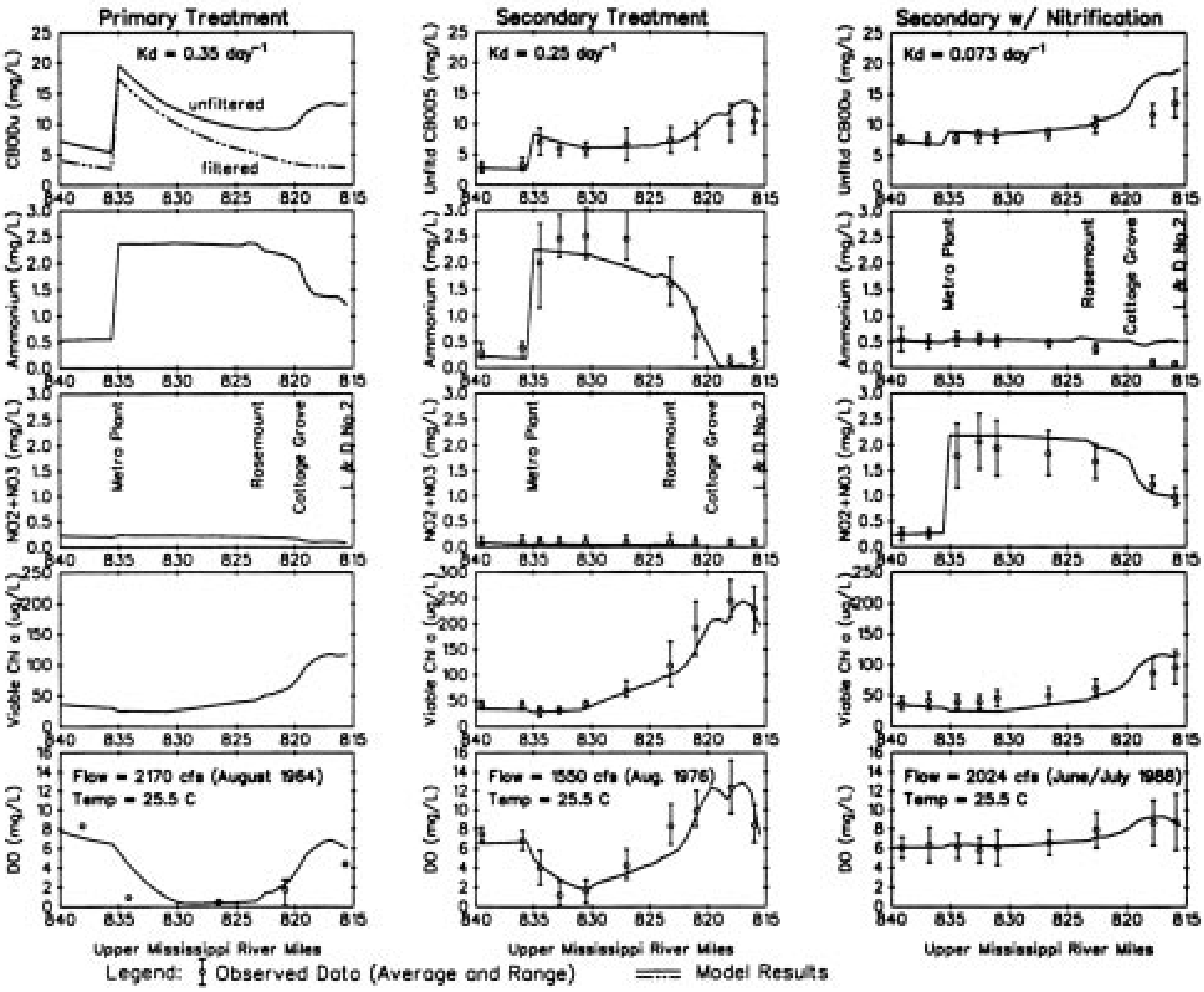


Figure 12-17

Improvement in ultimate CBOD, ammonia-N, and DO levels in the Upper Mississippi River related to Metro treatment plant upgrades from primary to secondary and advanced secondary with nitrification.

Source: Lung, 1998.

calibrated model to match observed water quality distributions that are directly related to changes in effluent loading from Metro under the three different treatment levels. The data used to define the effluent flow and loading characteristics for the primary, secondary, and advanced secondary treatment levels for the 1964, 1976, and 1988 simulations are given in Lung (1998). The data used to define effluent flow and loads from the other municipal and industrial point sources and the boundary inputs from the Upper Mississippi River and the Minnesota River are summarized by WRE (1975) for 1964 and by EnviroTech (1992, 1993) for the 1976 and 1988 simulations. In generating the simulation results for the three different treatment scenarios, all model coefficients, except the CBOD oxidation rate, are based on the same numerical values for each of the three model runs. The in-stream oxidation rate for CBOD is assigned different values for primary (0.35 day^{-1}), secondary (0.25 day^{-1}), and advanced secondary with nitrification (0.07 day^{-1}) since this kinetic reaction rate is dependent upon stabilization of the effluent and the quantity of labile and refractory components of oxidizeable organic matter in the effluent (Chapra, 1997; Thomann and Mueller, 1987). Using effluent loading rates that are representative of the three different treatment levels for Metro, the model results confirm that the improvement in water quality observed in the Upper Mississippi River can be attributed to investments in upgrading the Metro plant.

Impact of Wastewater Treatment: Recreational and Living Resources Trends

Long-term trends in recreational uses, private investments along the riverfront, and biological resources dependent on the integrity of aquatic ecological conditions are meaningful nonchemical indicators of water quality conditions in the Upper Mississippi River. One very simple indicator is the use of the river for recreational boating. If water quality conditions are very poor, as was the case during the 1950s and 1960s, the noxious conditions are not desirable for boating as a recreational activity. If water quality is not degraded, the river might be considered desirable for boating. As shown in the long-term trend of recreational boat traffic through Locks 1 through 4 of the river (Figure 12-18), annual recreational vessel usage of the river ranged from approximately 25,000 vessels to approximately 30,000 vessels from the mid-1970s through the mid-1980s. Beginning in the mid-1980s, the improvements in water quality in the Upper Mississippi River suggest a strong correlation with the dramatic increase in annual recreational vessel traffic on the river to approximately 45,000 to approximately 53,000 boats (Erickson, 2000), with the recreational vessel traffic in Locks 1 through 4 increasing by about two-thirds between 1986 and 1998 (Figure 12-18). Note that traffic in 1993 dropped by about one-half because of the extreme flood conditions of that

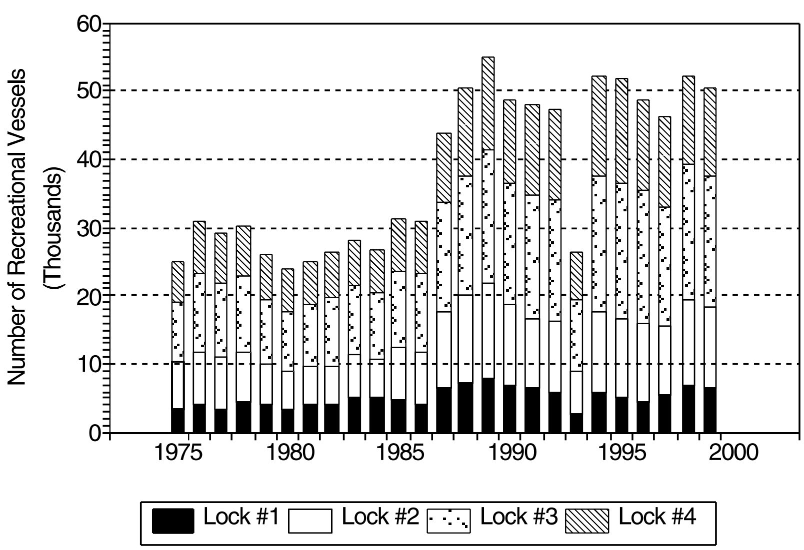


Figure 12-18

Recreational vessel traffic in Locks 1 through 4 of the Upper Mississippi River.

Source: Erickson, 2000.

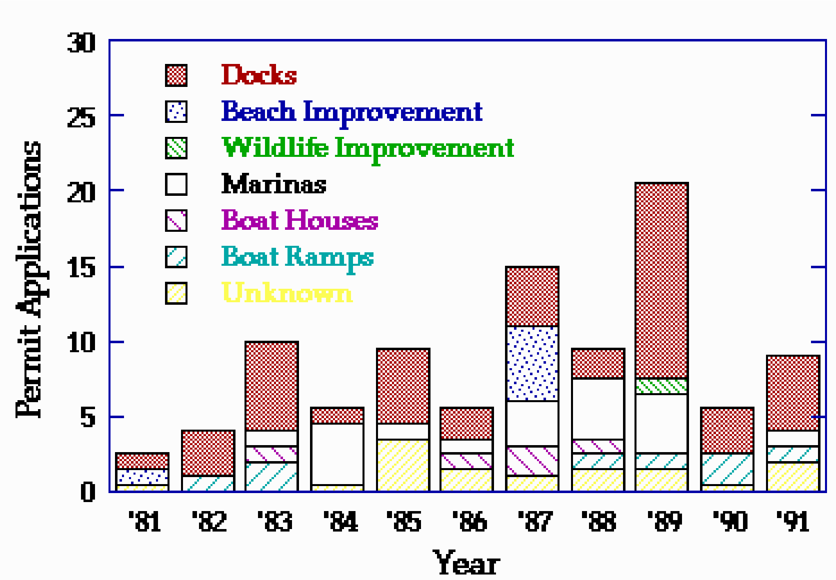


Figure 12-19

Recreational permit applications for Wabasha, Dakota, Washington, Goodhue, Pierce, and Pepin counties along the Upper Mississippi River.

Source: Erickson, 2000.

year.

Recreational boats require marina space, and in 1990 about 2,700 new marina slips were in various planning stages—enough to double marina capacity. The number of permit applications received by the St. Paul District U.S. Army Corps of Engineers for docks, marinas, boathouses, boat ramps, and beach and wildlife improvements soared from only 3 in 1981 to 22 by 1989 (Figure 12-19). In the late 1970s, nobody would have considered investing in a marina in Pool 2 because of poor water quality conditions in the vicinity of St. Paul. Apparently related to improvements in water quality conditions, several marinas were proposed and constructed for this area of the river beginning in the mid-1980s. Lake City, located on Lake Pepin, for example, obtained a permit for a new marina in 1984; within a year, several hundred spaces were added for sailboats.

Increases in recreational uses of the river prompted eight agencies to form a partnership agreement in 1990 to study recreational trends and resolve conflicts over river and parkland use. The agencies included two park services, three state DNRs, the U.S. Fish and Wildlife Service, the U.S. Army Corps of Engineers, and the Minnesota-Wisconsin Boundary Area Commission. They conducted a study to sort out the issues, uses, and resource management conflicts related to the rediscovery of the delights of a cleaned-up river by boaters, fishermen, and hikers (MPCA, 1993).

Partly because of the ban on DDT, the establishment of wildlife reserves, and reduced loadings of industrial pollutants from the pretreatment program, populations of water birds have increased in the Upper Mississippi River. Peregrine falcons, bald eagles, mallard ducks, and great blue herons have been observed in the Minneapolis-Saint Paul metropolitan area and in the floodplain wetlands located on the Upper Mississippi River near the Metro plant. Black crowned night herons have been observed feeding below the Ford Dam (Galli, 1992). Animals sensitive to the bioaccumulation of PCBs in their aquatic food, such as fish-eating mink, are also making a comeback (Smith, 1992). The number of great egrets and great blue herons nesting in Pig's Eye Lake has increased since the late 1970s and early 1980s, and cormorants has been observed nesting

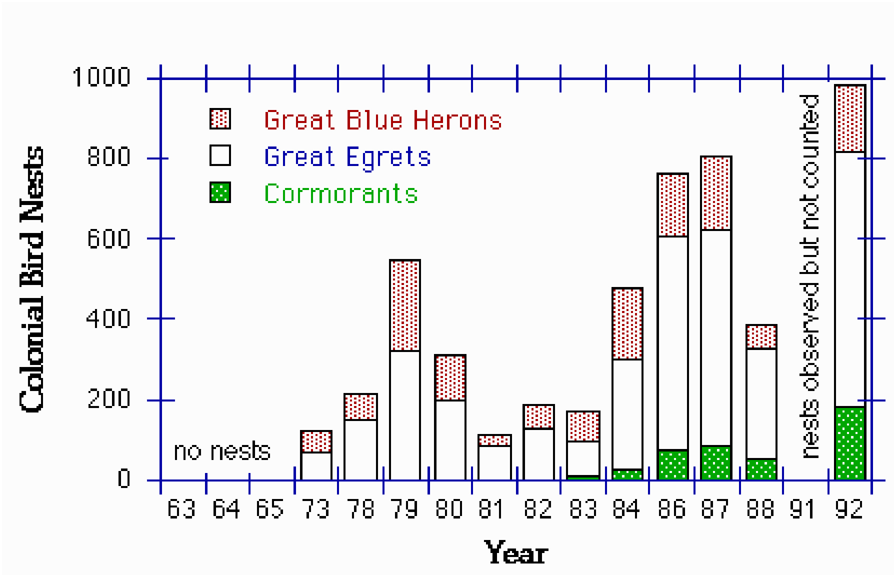


Figure 12-20

Colonial bird nest counts for Pig's Eye Lake.

Source: Galli, 1992.

in the lake since 1983 (Galli, 1992) (Figure 12-20).

Electrofishing samples from Spring Lake, a backwater area affected by the Metro plant, were collected in 1981, 1986, and 1991. These samples showed an increase in the species diversity and the abundance of certain species (Gilbertson, 1992). The ecological quality of Spring Lake, as expressed by the Index of Biotic Integrety (IBI) (Karr, 1981), has improved since the mid-1980s (Figure 12-21). Species that have returned to Pool 2 include blue sucker and paddle fish; this is particularly noteworthy because paddle fish had not been observed in Pool 2 since the 1950s.

As in many other urban waterways of the United States, detectable levels of PCBs, a toxic organic chemical that adsorbs to sediment particles, have been identified in fish tissue and sediments as a result of contamination from industrial sources, transport of contaminated sediments, atmospheric deposition, storm water runoff, and wastewater discharges. In 1975 PCB residues found in com-

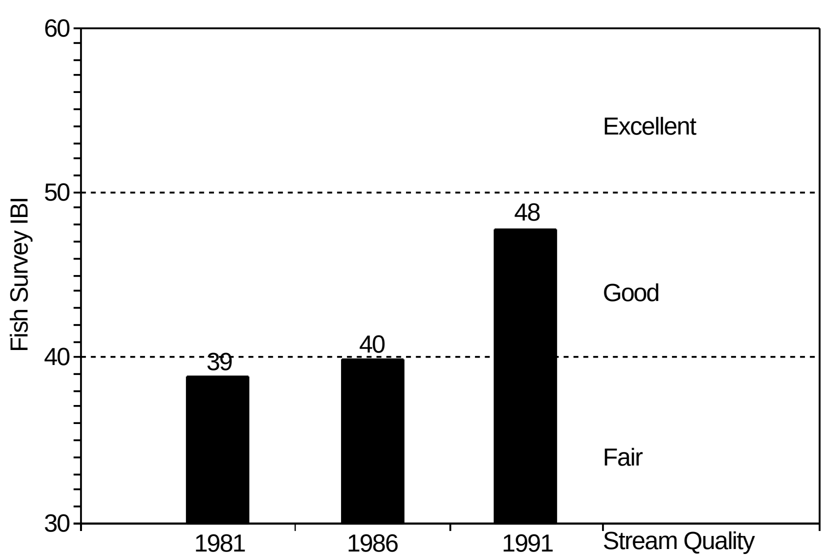


Figure 12-21

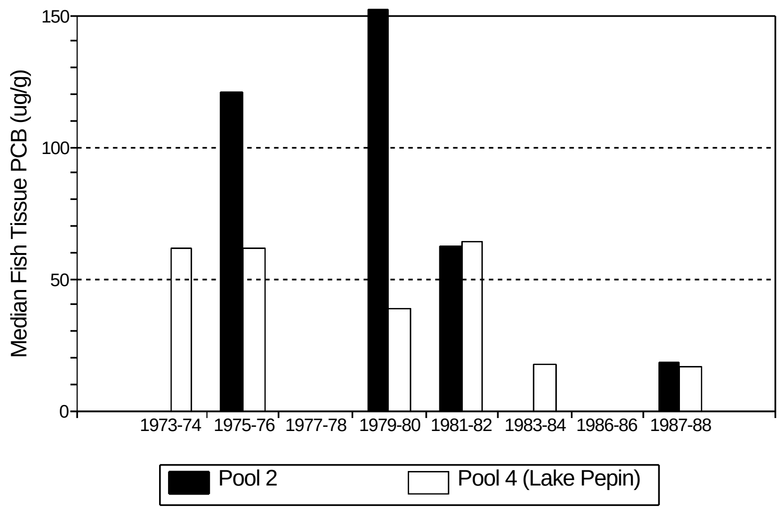
Fish survey results for Spring Lake, backwater to Pool 2, which receives discharges from the Metro wastewater treatment plant.

Source: Gilbertson, 1992.

Figure 12-22

Lipid-normalized median PCB concentrations in fillet tissue (skin on) of 20-24.9-inch carp from Pool 2 and Pool 4 (Lake Pepin) of the Upper Mississippi River, 1973-1988.

Source: Biedron and Helwig, 1991.



mon carp and other fish species taken from the Upper Mississippi River exceeded the FDA action level of 5 mg/kg. The Minnesota Department of Health issued fish consumption advisories for a number of species including common carp, catfish, walleye, and smallmouth buffalo (MDH, 1998). Since the ban on production of PCBs in 1979, the level of PCBs in fish tissue in the Upper Mississippi River, as well as in many other rivers and lakes in the United States, has been declining. In the Upper Mississippi River, median PCB levels in common carp and walleye dropped by over 80 percent during the period between 1975-1979 and 1988-1995. Dramatic decreases have been recorded in fish tissue levels of PCBs from common carp collected in Pool 2 and Pool 4 (Lake Pepin) of the river. Lipid-normalized median PCB concentrations have declined in Pool 2 from 121 µg/g in 1975-1976 to 18 µg/g in 1987-1988 and in Lake Pepin from 62 µg/g in 1973-1974 to 16 µg/g in 1987-1988 (Biedron and Helwig, 1991) (Figure 12-22). Low levels of PCBs still persist, however, in fish tissue and other chemical pathways in the aquatic environment, despite the PCB ban (Lee and Anderson, 1998).

Summary and Conclusions

As a result of strong state, local, and federal legislative actions with overwhelming public support, the cleanup of the Upper Mississippi River in the Twin Cities area is a national environmental success story. Comprehensive water pollution surveys dating back to 1926 documented the magnitude of the problems and provided the technical basis for the implementation of effective engineering proposals for abatement of water pollution in the river. Since enactment of the Clean Water Act in 1972, Minnesota has increased the water quality standard for DO to 5 mg/L and invested in upgrades to obtain better-than-secondary levels of wastewater treatment for the Metro plant and the other wastewater treatment plants operated by the MCES.

In contrast to the excessive effluent loading from the Metro plant during the 1960s, the investment in upgrades to the Metro plant during the 1980s, including nitrification, have succeeded in reducing effluent discharges of BOD_5 from 1968 to 1998 by 95 percent (Figure 12-9), suspended solids from 1968 to 1998 by 95 percent (Figure 12-10) and ammonia-nitrogen from 1982-1998 by 90 percent (Figure 12-11). As a direct result of these upgrades, compliance with water quality standards for DO has been achieved even under the low-flow conditions of the drought of 1988 (Lung, 1998). The accelerated program to separate storm water and sanitary flow succeeded in achieving compliance with state standards (200 MPN/100 mL monthly geometric mean and 2000 MPN/100 mL for individual samples) for fecal coliform bacteria at the 71 percent level for samples collected during 1996-1998. As a result of the industrial waste pretreatment program initiated in 1982, the discharge of heavy metals to the Metro plant (and the Upper Mississippi River) has been reduced by about 90 percent (MCES, 1999) and mercury loading from the Upper Mississippi River to Lake Pepin in 1990-1996 declined by almost 70 percent since the 1960s (Balogh et al., 1999). Despite these significant improvements, MCES has targeted toxic chemicals (e.g., PCBs) and heavy metals (e.g., mercury) as contaminants of concern for monitoring, identification of sources, and reduction of the load discharged to the river.

In contrast to the degraded environmental conditions during the 1950s through 1970s, the Upper Mississippi River is no longer a place to avoid. Parks, trails, and marinas have been developed along the river in areas where no one would have considered making such investments in the 1970s. A thriving riverfront corridor increases the value of both commercial and residential properties along the waterfront. The city of St. Paul, for example, through the St. Paul Riverfront Corporation, has invested nearly $500 million (as of the mid-1990s) for land acquisitions and infrastructure development along the riverfront (Donlan et al., 1995). In the late 1980s private developers began to respond to riverfront infrastructure investments by obtaining more than $7 million in tax increment financing for development along the riverfront (Donlan et al., 1995). In addition to private development, in December 1999 the Science Museum of Minnesota completed a new museum along the riverfront in St. Paul that features exhibits on the Upper Mississippi River.

The record clearly shows that the Clean Water Act of 1972 profoundly affected every community in Minnesota, including the Twin Cities. The CWA accelerated the cleanup of the Upper Mississippi River by providing federal funds for the construction of new wastewater collection and treatment systems and the upgrading of existing sewage treatment plants. Since the mid-1980s, the resurgence of mayflies and the record of greatly improved compliance with water quality standards for dissolved oxygen and fecal coliform bacteria are key indicators of the effectiveness of the water pollution control efforts accomplished by state, federal, and local governments in the Twin Cities.

By the end of 2005, the Metro plant will have implemented biological removal of phosphorus to meet an annual effluent level of 1 mg/L for phosphorus (MCES, 1998a). As of 1999 "BioP" had been successfully implemented in a portion of the Metro plant and at suburban plants discharging to the Minnesota River. Under the Metro Environment Partnership, the control of urban and rural runoff will be addressed by a $7.5 million commitment from the MCES to reduce pollution from the seven-county Twin Cities metropolitan region (MCES, 1998a). State-of-the-art technology for solids processing, approved in July 1998, will reduce mercury emissions by 70 percent along with other pollutants and odors (MCES, 1998a). Further reductions in mercury discharges to the river from the

Metro plant will be accomplished as a result of a partnership between the MCES and the Minnesota Dental Association to test and evaluate new technologies to filter dental amalgam from wastewater (MCES, 1998b, 2000).

Although significant accomplishments have been made to improve water quality and ecological conditions in the Upper Mississippi River, continued investments are needed to address contemporary issues for continued restoration and maintenance of the ecological integrity of the river. The designation of the Upper Mississippi River as an American Heritage River in July 1998 recognizes both the significant environmental improvements that have been accomplished and the continuing need to address the key ecological issues identified in the 1990s. The key water quality and resource management issues identified for the Upper Mississippi River (USGS, 1999b) for the 21st century include the following:

- Point and nonpoint source loading of nutrients, sediments, heavy metals, and toxic chemicals in the Minnesota River and Upper Mississippi River from agricultural and urban land uses.
- Point and nonpoint source loading of nutrients and pesticides to aquifer systems from agricultural land uses.
- Contamination of ground water with toxic chemicals from industrial activities and leachate from landfills.
- Contamination of surface waters and ground water in areas characterized by rapid urbanization.
- Degradation of biological communities by riparian and bottom habitat losses, river channel modifications, construction of locks and dams, increasing backwater sedimentation rates and loss of wetlands, effects of reservoir operations on fisheries, and eutrophication.
- Contamination of bottom sediments in the river with toxic chemicals and subsequent benthic release and bioaccumulation of toxic substances within the aquatic food chain.

Water quality in the Upper Mississippi River, as measured by indicators presented in this chapter such as DO, ammonia, fecal coliform bacteria, and sediment levels of mercury, has improved greatly since the 1960s and 1970s as a result of upgrades to wastewater treatment plants required by the 1972 CWA. Despite these improvements, contaminant loading from municipal (nutrients) and industrial (heavy metals, toxic chemicals) dischargers and runoff from urban (heavy metals) and agricultural (nutrients, pesticides, sediments) watersheds continue to adversely affect the ecological integrity of the Upper Mississippi River. In addition to chemical inputs to the river, the Upper Mississippi River Conservation Committee has warned that the ecosystem of the Upper Mississippi River is threatened by structural alterations of the river such as continued stream channelization, flood control levees that separate the river from the floodplain, and the proposed expansion of the commercial navigation infrastructure (UMRCC, 1994). If the current ecological benefits are to be maintained and degraded ecological conditions restored, an ongoing effort will be needed to maintain environmental monitoring and research programs to document the status and trends of the Upper Mississippi River to provide the scientific data needed for effective resource management decisions (USGS, 1998).

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